"Study of the evolution of the seismic cycle of stress and strain to the El Salvador Fault Zone (ESFZ)"

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GNS Science
Earthquakes Volcanoes Tectonics Section

Universidad de Cantabria
Enviromental Hydraulics Institute

Research lines

Active Tectonics

- Paleoseismology
- Geodesy
- Numerical Modelling

Geological Hazards

- Seismic Hazard
- Landslides
- Tsunamis
- Volcano-Tectonics

Main areas of study

- Central America:
  - Regional studies in Central America (Seismic Hazard).
  - El Salvador Fault Zone (ESFZ).
  - Aguacaliente-Navarro Fault Zone (ANFZ), Central Valley of Costa Rica.
  - Haiti (seismic hazard)
- Spain:
  - Regional-Nacional studies of seismic hazards (applications to building codes, eurocode, emergency plans, etc.)
  - Betic range zone, south of Spain.
  - Ibero-Maghrebi region (collision zone).

Main funding sources

- **AECID** (Agencia Española de Cooperación Internacional y Desarrollo – Spanish Agency of International Cooperation and Development)
- **UPM** (Universidad Politécnica de Madrid – Technical University of Madrid)
- **MCyT** (Ministerio de Ciencia y Tecnología de España - Ministry of Science and Technology of Spain).

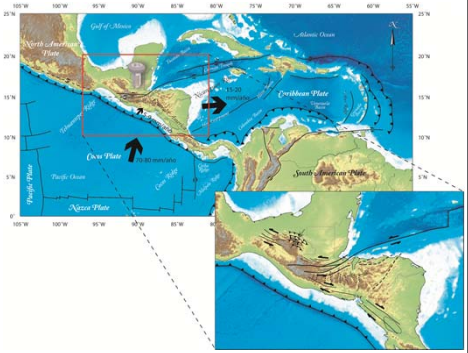
Main Objetives in El Salvador

- Paleosesimic analysis of El Salvador Fault Zone (ESFZ), Central America.
- Current crustal deformation of El Salvador Fault Zone from GPS data.
- Kinematic model of the El Salvador Fault Zone from geological, seismological and geodetic data.
- Seismic hazard maps.

With the collaboration of SNET (Servicio Nacional de Estudios Territoriales), MARN of El Salvador.

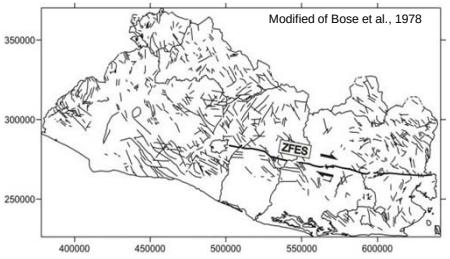
Seismotectonic Setting

The seismogenetic zone of El Salvador is located in the Cocos-Caribbean subduction zone in Central America, where the velocity of plate convergence is ~ 73-84 mm/y (DeMets, 2001).



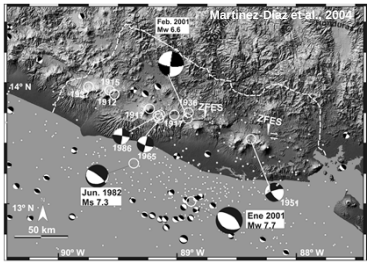
Seismotectonic Setting

- El Salvador is characterized by seismic active strike slip faults subparallel to the subduction zone.
- These faults are responsible of the most destructive earthquakes have occurred along the Pacific coast in the Central American volcanic arc, from Guatemala to Costa Rica.
- The models estimate velocities of movement parallel to the arc around ~ 10-15 mm/y. (White 1991, DeMets 2001; Guzman-Speciale, 2001, Dewey et al. 2004, Lyon Caen 2006, Turner et al. 2007)



Seismotectonic Setting

- There are two types of seismicity in terms of tectonic origin and location in this area:
  - The largest earthquakes (Mw > 7) are generated in the subduction zone along the boundary of the Cocos and Caribbean plates. These earthquakes occur at intermediate depths (~ 200 km), causing moderate damage to the continent.
  - Earthquakes on the mainland occur along the El Salvador volcanic arc with magnitudes up to Mw 6.7. These events present superficial character being more destructive than those of the subduction zone, despite its smaller magnitude.



Historical destructive earthquakes (white circles) and instrumental epicenters (Ms >2.5, period 1977–2001) from U.S. Geological Survey–National Earthquake
Information Center (USGS-NEIC) catalogue (small dots). Small focal mechanisms are from events with Mw >5.5 (period 1977–2001, Harvard Centroid Moment Tensor database). Large mechanisms are from Buforn et al. (2001).

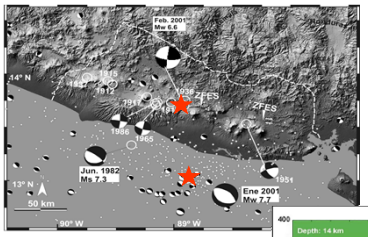
Seismic effects

- El Salvador has suffered at least 11 destructive earthquakes over the last 100 years causing over 3000 deaths, due to both the direct effect of seismic and the induced landslides.

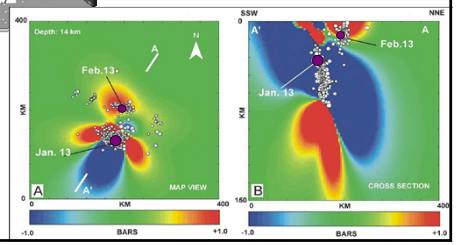
2001 El Salvador earthquakes:

- < 1000 deaths
- Thousands of displaced
- Destruction of basic infrastructures

Study of the Coulomb Failure Stress transfer after the 13 January event



Could the 13 february earthquake be triggered by the CFS after 13 January event?



Results of CFS modelization

The focus of the 13 February is located in a loaded zone after the January event

(Martinez-Diaz et al., 2004)

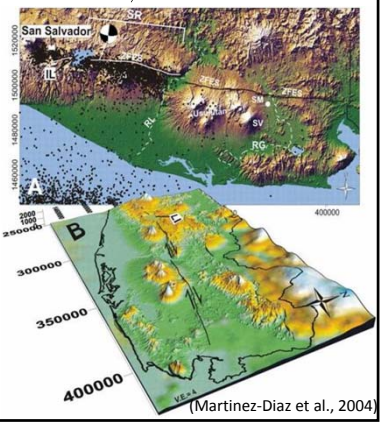
13th February Mw 6.6 El Salvador Earthquake

SR was broken by the february 13 th and aftersocks

Seismotectonic regional interpretation

El Salvador Fault Zone (ESFZ) definition

- From the earthquakes of 2001 identified the existence of an active fault with dextral strike-slip motion and length greater than 150 km which crosses the country from east to west with an average direction N100 °.
- Responsible for the destructive seismicity of the volcanic zone.
- Source of important earthquake of volcanic chain.



(Martinez-Diaz et al., 2004)

Objetives

Study of the seismic cycle of the ESFZ, a major tectonic structures in the region and possibly the structure which is accommodating most of the motion parallel to the subduction zone

Paleoseismic analysis of ESFZ: characterization of pre-historical behaviour of the ESFZ

Study of the current deformation in ESFZ from GPS data

To improve the **evaluation of seismic hazard** in this area

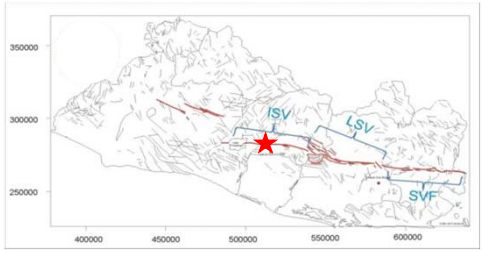
PALEOSEISMIC ANALYSIS OF EL SALVADOR FAULT ZONE

Carolina Canora, José Martínez-Díaz, Ramón Capote, Pilar Villamor, K. Berryman, J. M. Insua Arévalo , J. Alonso-Henar.

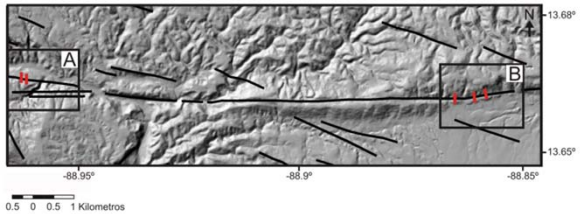
PALEOSEISMIC ANALYSIS OF EL SALVADOR FAULT ZONE

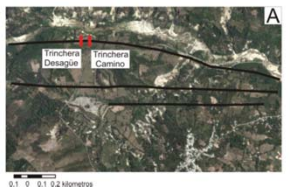
- Identification and characterization of the earthquake source: ESFZ
- Analysis of the neotectonic setting of this source
- Characterization of pre-historical behaviour of the ESFZ

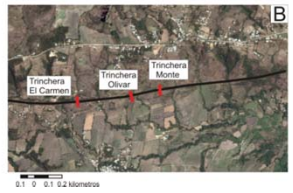
The Ilopango-San Vicente segment was responsible for the earthquake of February 2001 (Mw 6.6)

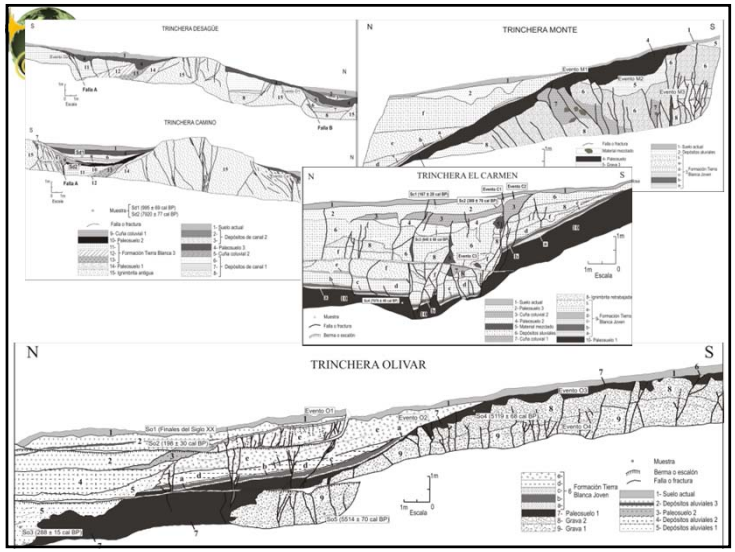


Paleoseismic analysis of the San Vicente segment

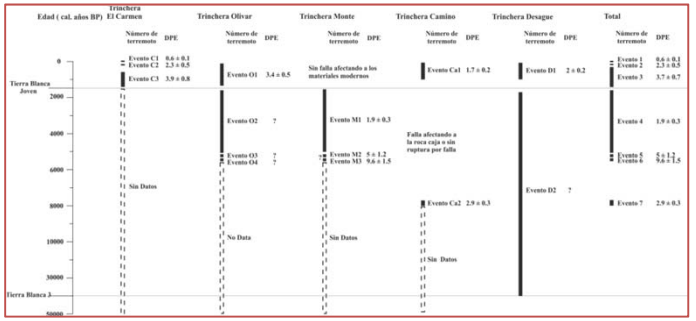








Earthquake history and slip rate



- Trenching at five sites along the San Vicente segment shows that surface fault rupture has occurred at least seven times during the past 8.000 years.
- Single-event displacements identified at each trench vary from several decimetres to at least 3.7 m.

Maximum earthquake magnitude, rupture recurrence and historic seismicity: earthquake hazard

- Fault trace mapping, geomorphic analysis, and paleoseismic studies indicate a maximum magnitude for the El Salvador Fault Zone is Mw 7.6, with a recurrence interval of around 800 yr.
- Combining displacements of river courses and the timing of events revealed in the trenches, we calculate a slip rate of 4mm/yr for El Salvador Fault Zone, identifying the fault zone as a major tectonic feature of the region.

Min. slip rate (mm/año) for the San Vicente segment of El Salvador Fault Zone based on paleoseismic trenches.

Source	Displacements	Age (aprox.)	Slip rate
Trenches	6 ± 1 m 23 ± 4 m 26 ± 4 m	Last 1.500 years Last 5.500 years Last 8.000 years	4.1 ±0.6 4.1 ± 0.7 3.2 ± 0.5

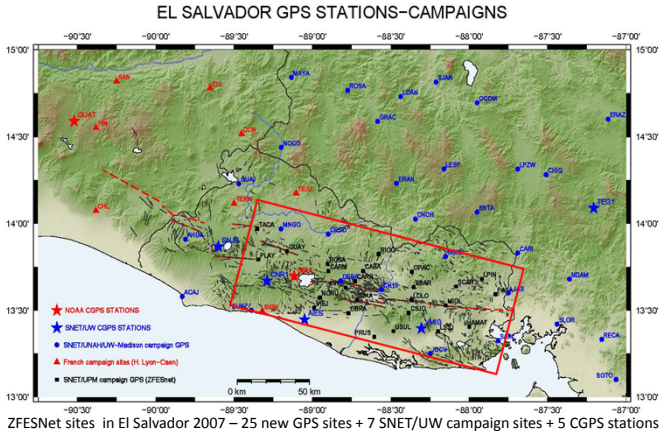
STUDY OF THE DEFORMATION IN EL SALVADOR FAULT ZONE FROM GPS DATA

Alejandra Staller Vázquez, Douglas Hernández, Belén Benito, Manuel Díaz, Carlos Pullinger

STUDY OF THE DEFORMATION IN EL SALVADOR FAULT ZONE FROM GPS DATA

- Objetives:
  - To define a GPS network (ZFESNet), complementary to paleoseismology studies, in order to study the existence of **current deformation at the ESFZ surface**.
    - To quantify the interseismic deformations associated with the activity of the ESZF.
    - Characterization of current behaviour of the ESFZ (locking, creeping…)
    - To complete the geological data (slip rate)
  - To contribute to the development of precise models in the region.

ZFESNet - Sites location



ZFESNet sites in El Salvador 2007 – 25 new GPS sites + 7 SNET/UW campaign sites + 5 CGPS stations
Red rectangle show the study area

GPS Campaigns

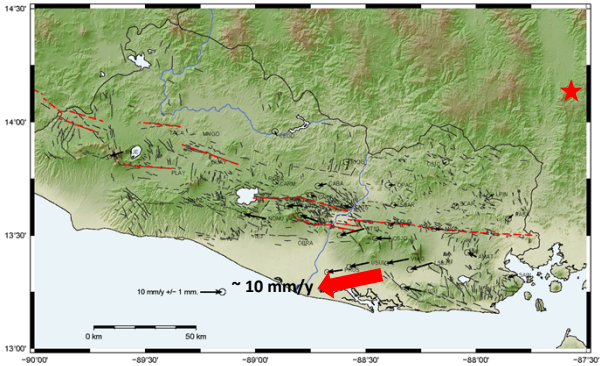
- 3 Campigns (Nov-2007, Nov-2008, May-2010)
- Next campaign Feb-2012.
- The static GPS method was performed during periods of ~ 24 hour sessions (problems for longer sessions).
- During the observation period the receivers were kept (Salvadoran armed forces).
- In most cases, sites were occupied two different sessions in order to minimize systematic local or user errors.

GPS Campaigns

- We have used three types of GPS antenna mounts on the GPS sites:
  - Standard Tripod with Tribrach and Rotating Optical Plummet (only in the 2007 campaign).
  - Fixed-length poles 1,1265 m.
  - Fixed-Height Spike Mount 0,55 m.

Preliminary results

PRELIMINARY RESULTS 2007–2010



* Only sites with 3 campigns

Preliminary results

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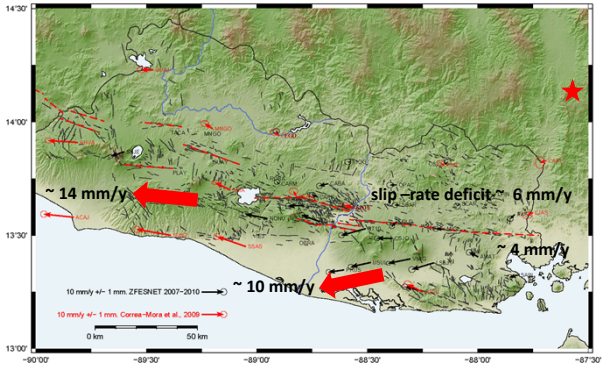

Preliminary results

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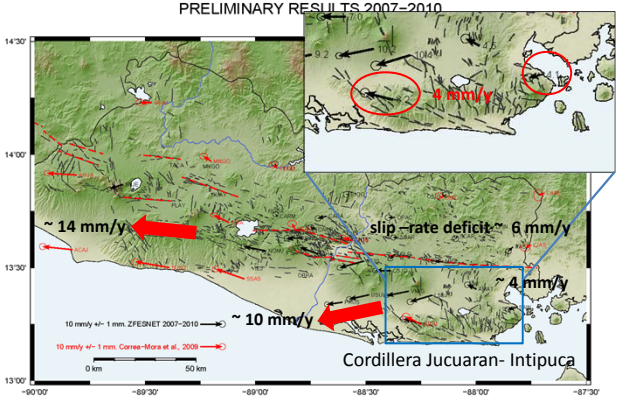

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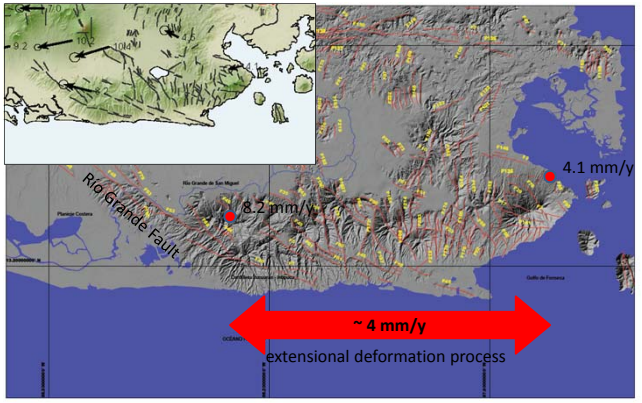

Cordillera Jucuaran- Intipuca

Conclusions

- The paleosesimology and GPS studies confirm the kinematics of strike slip with normal component of the ESFZ.
- The rupture of the San Vicente segment is the seismic source of the February 2001 earthquake.
- The rupture was a 21 km long on a E-W, 70º-80º dip, dextral strike- slip fault plane.
- Coseismic surface rupture occurred along the segment with a maximum displacement of **0.6 m** that decreases towards the east.

Conclusions

- The main faults in the San Vicente segment form a dextral strike slip system capable of generating earthquakes with magnitudes > Mw 7.
- We have evidence of at least 7 surface rupture earthquakes over the past 8,000 years.
- The paleoseismic analysis shows that the San Vicente segment slip rate is ~ 4 mm/y and the recurrence intervals are ~ 750 years for the largest earthquakes.
- Preliminary geodetic results show slip rate of San Vicente segment is ~ 10 mm/y.

?

Deficit slip-rate

Conclusions

- Along the Cordillera Jucuarán - Intipuca range and vicinity, it is evident the occurrence of an extensional deformation process in the direction E - W limited on the west by faults of NW - SE and north of the faults that define the San Miguel segment of the ESFZ.
- This process operates at a velocity of ~ 4 mm /y.
- There is a slip-rate deficit ~ 6 mm/y in the San Miguel-Fonseca Segment, could be concentrated in the NW-SE and N-S structures.
- This confirms the transfer of deformation from the western segment ESFZ to these regular secondary structures near the eastern termination of the fault zone.
- Remark the importance of these structures N - S.



Muchas gracias por su atención